M-37 and M-115
Wexford County
Road Safety Audit

Michigan Department of Transportation

MDOT

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August 2011

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ROAD SAFETY AUDIT:

M-37 and M-115
Wexford County

FINAL REPORT

Opus International Consultants Inc.

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1.0 Introduction

The Michigan Department of Transportation (MDOT) retained Opus International Consultants Inc. (Opus) to lead an Operational and Preliminary Design Stage Road Safety Audit (RSA) at the intersection of M-37 and M-115 in Mesick. The objectives of this study were to conduct a formal safety performance examination of the study intersection with an independent, multi-disciplinary team. RSA's are a proactive approach to addressing safety of all road users and involve identifying both safety issues and developing mitigation measures.

This RSA followed the eight-step process which is detailed in Figure 1 below.

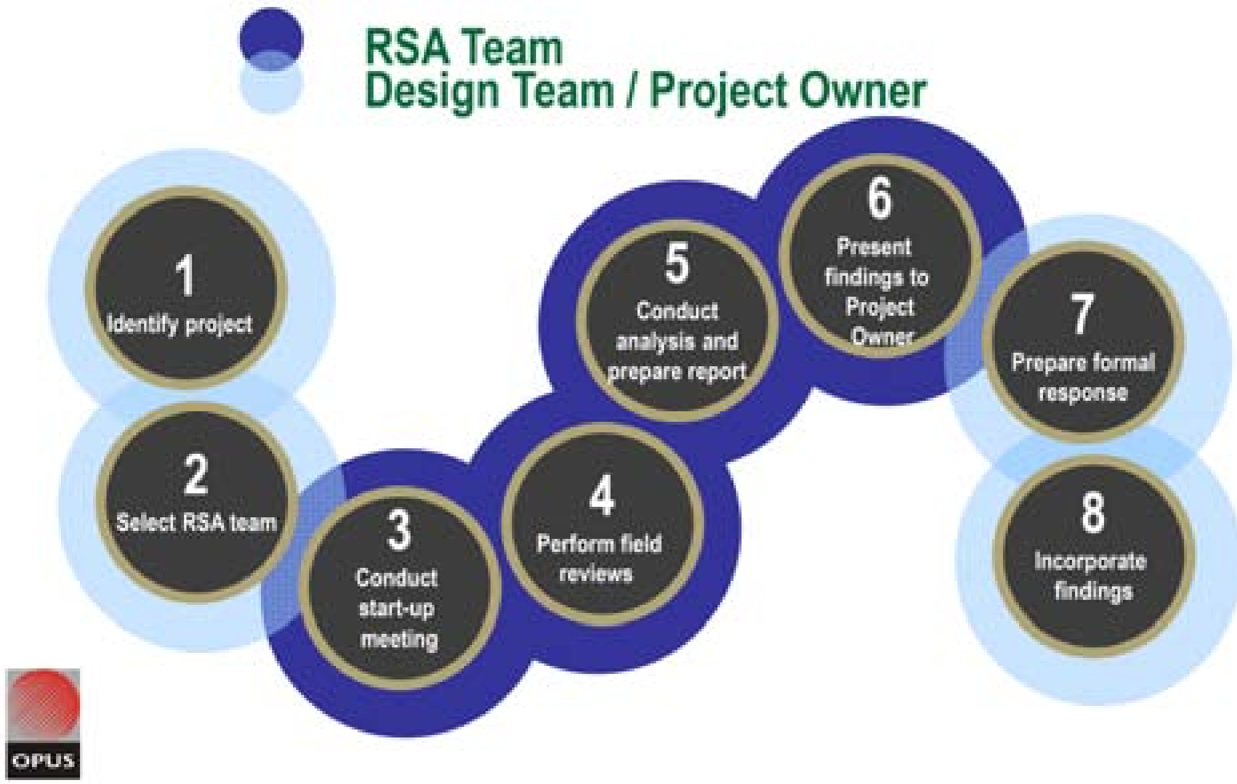


Figure 1 - RSA 8 Step Process

The following sections will detail the RSA process, the methodology for this analysis, and data obtained throughout the study. The report will also present all significant findings and safety issues as well as provide recommended mitigation strategies.

1.1 Background

The intersection analyzed in this report is the eastern intersection of M-115 and M-37 is circled in blue in Figure 2. This intersection was chosen by MDOT for safety assessment on the basis of crash history.

The objectives of the safety study are to:

- review traffic operations and safety at the intersection;
- identify physical and operational problems that may affect traffic safety;
- develop and evaluate potential countermeasures to reduce the frequency and severity of collisions.

Figure 2 - Study Intersection

Source: *www.michigan.gov/mdot/*

2.0 Road Safety Audit

2.1 Road Safety Audit Team

An RSA is a formal safety performance examination of an existing or future road or intersection by an independent audit team. RSA's help promote road safety by identifying safety issues during the planning, design, and implementation stages, promoting awareness of safe design practices, integrating multimodal safety concerns, and considering human factors.

Location:	Mesick, MI	
Audit Team Members:	Cynthia Redinger, P.E.	Opus International Consultants
	Samantha Cook, EIT	Opus International Consultants
	Dustin Cotter	MDOT
	Jeffery Barsch	MDOT
	Steve Stramsak	MDOT
	Dick Johnson	Retired Police Officer
Project Owner:	Michigan Department of Transportation	
Review Date:	April 11, 2011	
Audit Stage:	Operational and Preliminary Design Stage RSA	
Start Up Meeting:	April 11, 2011	
Preliminary Findings Meeting:	April 12, 2011	
Attended by:	Michigan Department of Transportation	
	Cadillac TSC	
	Opus International Consultants	
	Attorney General, Transportation Division	

The RSA team members conducted this audit to the best of their professional abilities within the on-site time available and by referring to provided information. While every attempt has been made to identify significant safety issues, the project owner is reminded that responsibility for the design, construction, and performance of the roadways remains with the agency with jurisdictional authority.

2.2 Road Safety Audit Materials

The RSA was based on the following data and analyses:

Site Review **–** Site visits were conducted on April 11, 2011 to review the intersection geometry and adjacent land use and to observe traffic operations and conflicts.

Traffic Counts: Annual Average Daily Traffic counts, hourly traffic counts, and turning movement counts from 2008 through 2010 were provided by MDOT.

Operational Analysis **–** RODEL Software was used to model the performance of the proposed roundabout condition at the study intersection. Preliminary design plans were provided by MDOT showing the geometric layout of the proposed roundabout.

Review of Crash Data and Analysis of Crash Trends **–** Crash reports were provided by MDOT for three years from 2008 to 2010. Predictive modeling was applied to the intersection using the site-specific Empirical Bayes (EB) Method from the *Highway Safety Manual (HSM) Volume 2* to determine the crash reduction benefits of a roundabout installation.

Identification of Improvement **–** On the basis of the above tasks, intersection safety issues and potential crash causes were identified. Suggested improvements were identified to address the safety issues and possible crash causes.

Economic Evaluation: An economic evaluation of the suggested improvements was conducted to estimate the potential societal benefits.

Project Data and Documents Available for the RSA:

- Crash reports and data
- 24-hour traffic counts
- Intersection turning movement counts
- Office memorandum files including a Synchro analysis of existing non-signalized and proposed signalized conditions
- Intersection notes revised on 4/8/2011
- Email correspondence
- Signal warrant evaluation
- Condition diagram
- Proposed Intersection Designs: single lane roundabout plan; realigned intersection design
- Right-of-way map
- Photos

All documents were provided from MDOT prior to or at the RSA workshop on April 11, 2011.

2.3 Road Safety Audit Team and Process

Site visits were conducted on April 11, 2011 to gain an understanding of the existing conditions and surroundings, observe road user behavior, and to identify existing safety concerns.

A road safety audit framework was applied in both the analysis and presentation of findings. The expected frequency and severity of crashes caused by each safety issue have been identified and rated according to categories shown in Table 1 and Table 2. These two risk elements were then combined to obtain a risk assessment on the basis of the matrix shown in Table 3. Consequently, each safety issue is assessed on the basis of a ranking between F (highest risk and highest priority) and A (lowest risk and lowest priority). For each safety issue identified, possible mitigation measures have been suggested.

Table 1 - Crash Frequency

Estimated		Expected Crash Frequency (per audit item)	Frequency Rating
Exposure	**Probability**		
High	High	10 or more crashes per year	Frequent
Medium	High		
High	Medium	1 to 9 crashes per year	Occasional
Medium	Medium		
Low	High		
High	Low	Less than 1 crash per year, but more than 1 crash every 5 years	Infrequent
Low	Medium		
Medium	Low	Less than 1 crash every 5 years	Rare
Low	Low		

Table 2 - Crash Severity

Typical Crashes Expected (per audit item)	Expected Crash Severity	Severity Rating
Crashes involving high speeds or heavy vehicles, pedestrians, or bicycles	Probable fatality or incapacitating injury	Extreme
Crashes involving medium to high speed; head-on, crossing, or off-road crashes	Moderate to severe injury	High
Crashes involving medium to low speeds; left-turn and right-turn crashes	Minor to moderate injury	Moderate
Crashes involving low to medium speeds; rear-end or sideswipe crashes	Property damage only or minor injury	Low

Table 3 - Crash Risk Assessment

Frequency Rating	Severity Rating			
	Low	Moderate	High	Extreme
Frequent	C	D	**E**	**F**
Occasional	B	C	D	**E**
Infrequent	A	B	C	D
Rare	A	A	B	C

Crash Risk Rankings -

A: minimal risk level

B: low risk level

C: moderate risk level

D: significant risk level

E: high risk level

F: extreme risk level

3.0 Intersection Characteristics

3.1 Study Location

The study intersection of M-115 and M-37 is just outside Mesick, MI, and is surrounded by gas stations and small businesses. M-115 is classified as a principal arterial on the east leg and a minor arterial on the west leg. M-37 is classified as a principal arterial on the north leg and a local road on the south leg. A schematic drawing of the intersection is shown in Figure 3, and site photographs are provided in Figure 4.

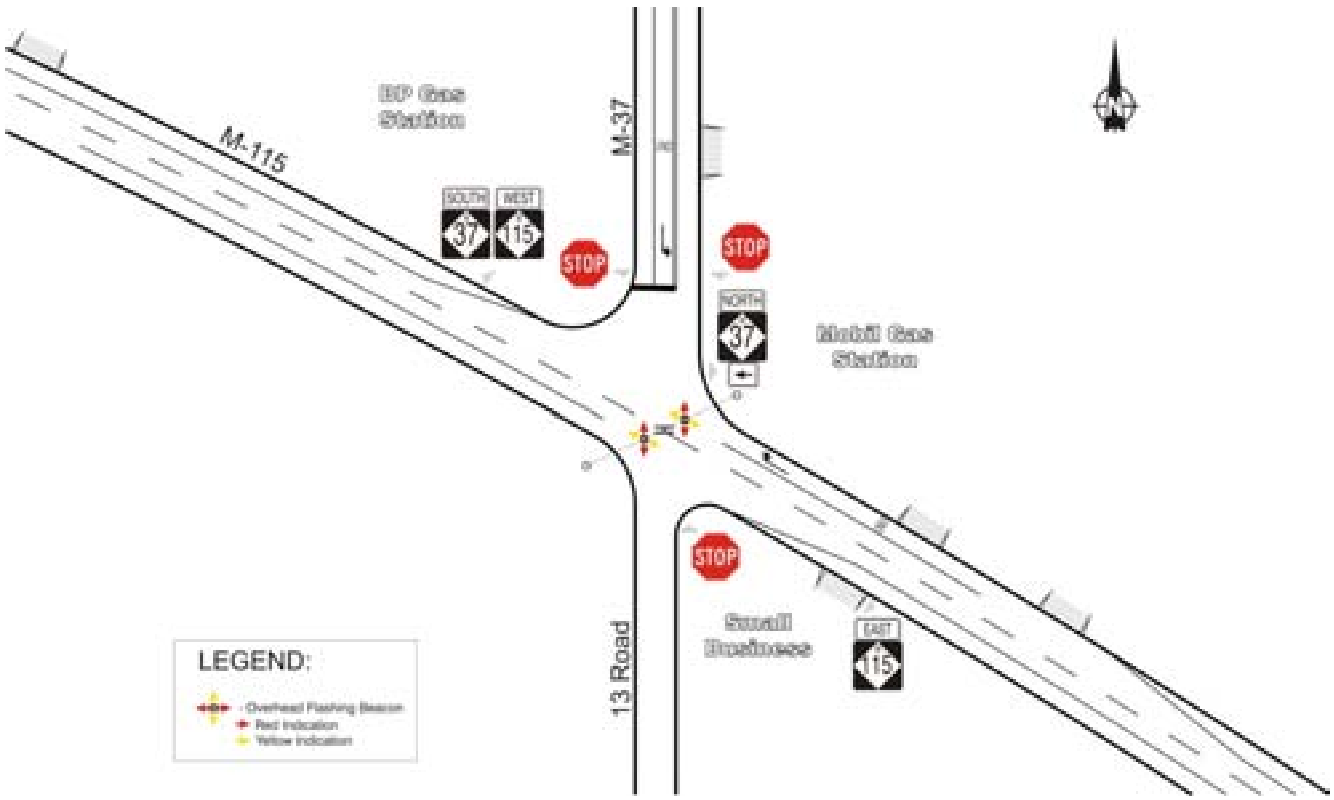


Figure 3 - Intersection Layout

Site Observations

- The south leg is an unpaved road with an un-posted speed limit.
- The posted speed limit is 55 mph on the north, east and west leg.
- Passing flares exist on the eastbound approach.
- Pavement markings were observed to be in poor condition during the site visit.

Northbound approach along M-37

Southbound approach along M-37

Eastbound approach along M-115

Westbound approach along M-115

Figure 4 - Site Photographs

3.2 Traffic Control

The intersection is two-way stop controlled. M-37/13 Road is stop controlled while M-115 is free-flowing. Double posted STOP signs are provided for the southbound approach. Two overhead flashing beacons are displayed for each approach to provide additional conspicuity of the intersection and the traffic control. A case sign is also displayed to provide an additional STOP sign for the northbound and southbound approach.

3.3 Traffic Volumes and Capacity

Currently this intersection operates with one through lane on each approach. A dedicated left-turn lane is provided on the southbound approach and a dedicated right-turn lane is provided on the eastbound and west-bound approaches. Annual average daily traffic (AADT) is 9,500 vehicles/day on M-115 (west of intersection) and 4,200 vehicles/day on M-37 (north of intersection). Turning movement counts for the AM and PM peak hour are summarized in Figure 5.

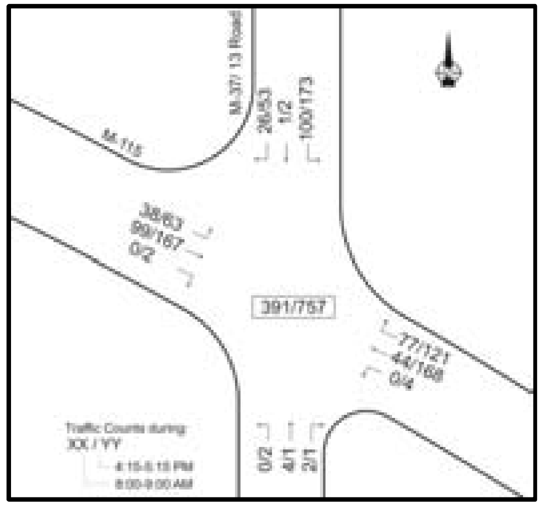


Figure 5 - Turning Movement Counts

3.4 Road User Characteristics

A variety of travel modes were observed, listed below:

Passenger cars, reflecting use by residents of Mesick and through traffic traveling on M-115 and M-37 were observed. The north leg of M-37 is a main route to Traverse City.

Trucks traveling through Mesick, consisted of semi-trucks and logging trucks utilizing the major routes at the intersection. Trucks contribute to large turning radii and may be a potential hazard by limiting sight distance at the intersection. Heavy truck volumes were observed utilizing the intersection.

Snowmobiles are present during the winter and are used to travel within the community and for recreation. A snowmobile trail exists on the west side of 13 Road and crosses M-115 west of the intersection and continues west. A snowmobile staging area is also located behind the BP gas station. Separate facilities for this different mode reduce interactions between the different road user types and speed variations. This lessens the likelihood of a severe injury crash occurring.

Non-motorized road users were an infrequent occurrence at the intersection. A bicyclist was observed traveling on M-115. Current accommodations, such as paved shoulders, are adequate for infrequent use.

3.5 Collision Analysis

Crash reports for the years of 2008 through 2010 were provided by MDOT. Over the three-years analyzed, 17 collisions were recorded at or near the intersection. As summarized in Figure 6, 30 percent of collisions resulted in at least one injury. One fatal collision was reported during the study period which accounted for 6 percent. The remainder of the collisions resulted in a property damage only collision. The crash rate was calculated to be 1.13 crashes per million entering vehicles.

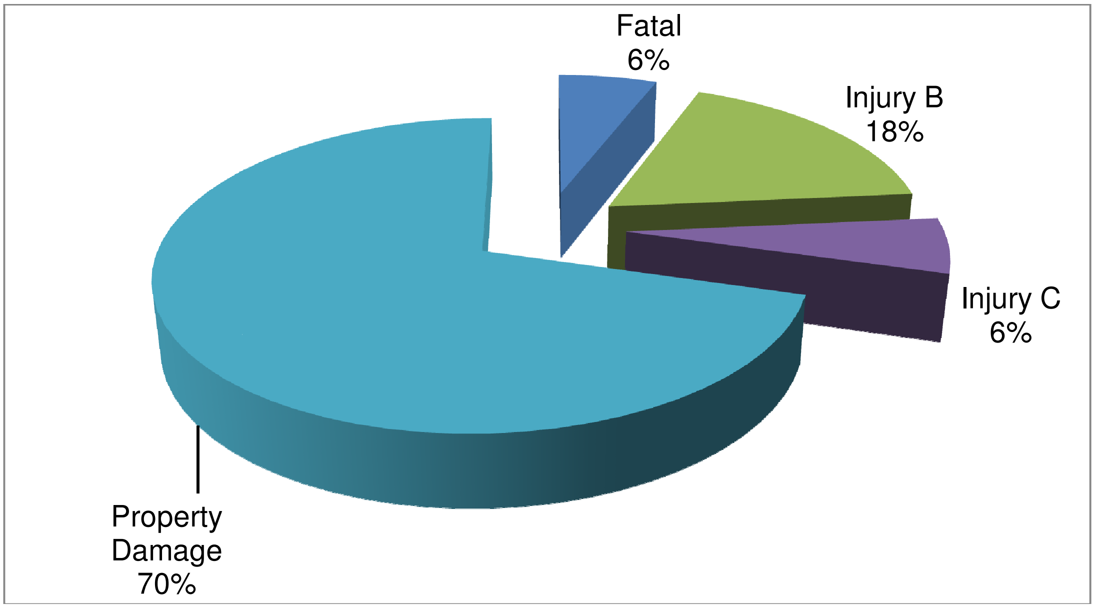


Figure 6 - Collision Severity Distribution

Collision Types

Collision type distribution is summarized in Figure 7, and spatial distribution is shown in Figure 8. The following collision trends are observed:

- The most prevalent crash type was angle collisions accounting for 47% of reported collisions during the analysis period. The majority of angle collisions involved the southbound through movement and the westbound through movement.
- Two angle collisions involving a motorcycle occurred at the intersection. Both involved a motorcycle traveling in the westbound direction and a vehicle traveling in the southbound direction. One of these crashes resulted in two fatalities who were passengers on the motorcycle.

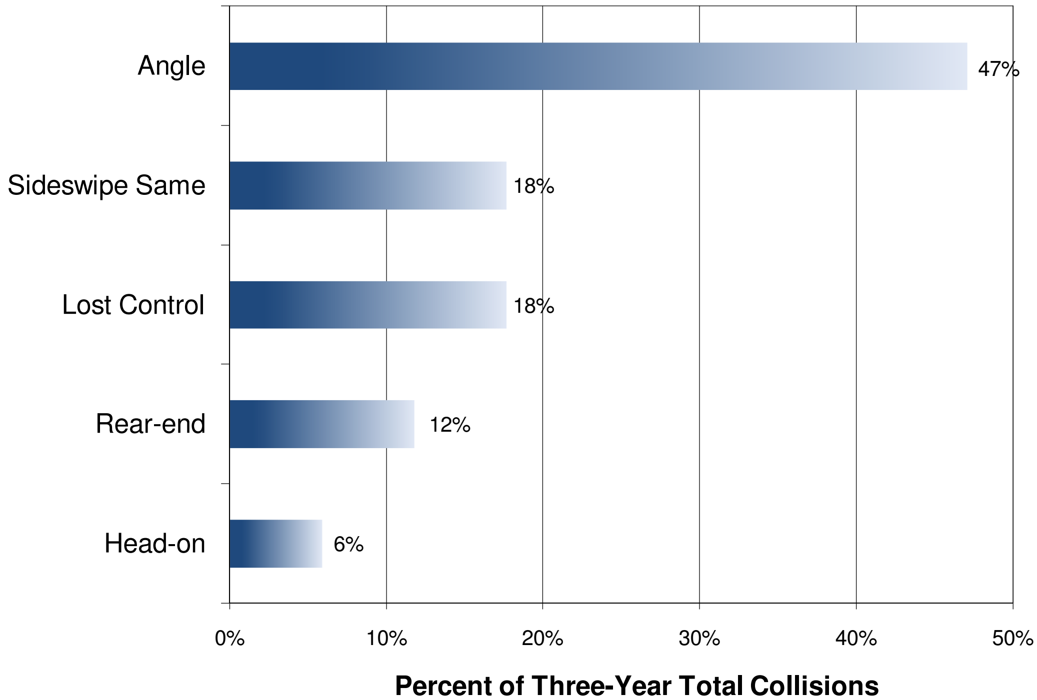


Figure 7 - Collision Type Distribution

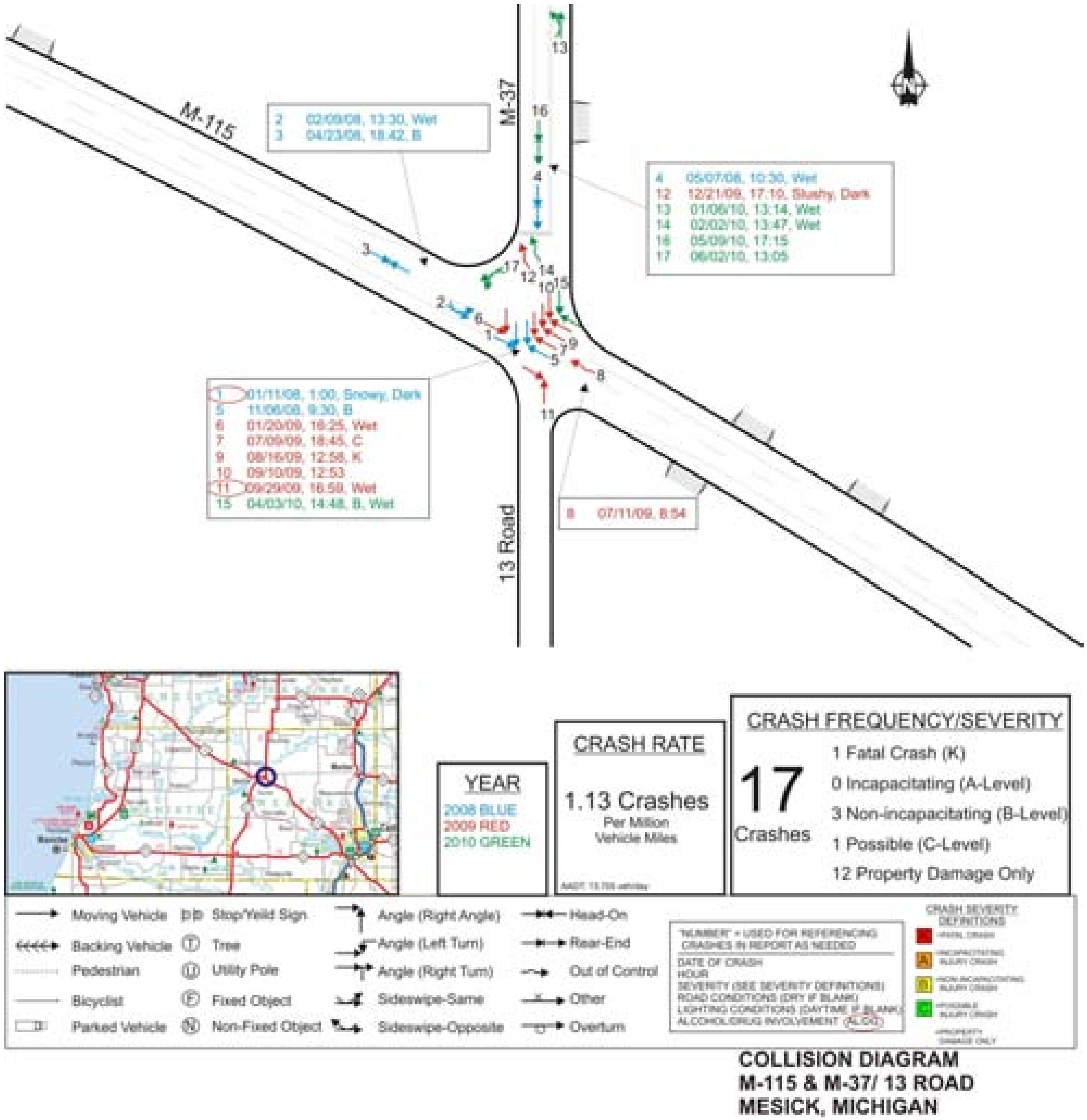
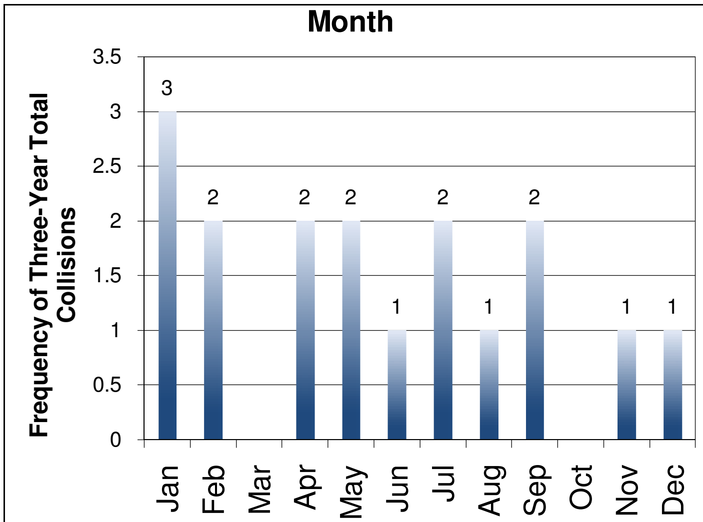
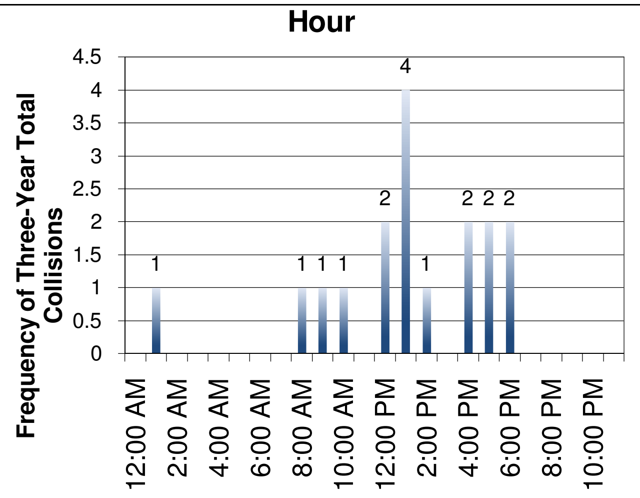


Figure 8 - Crash Diagram

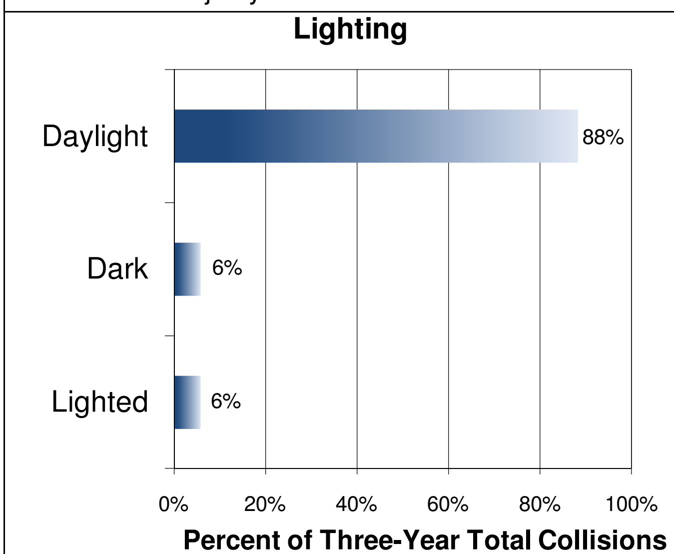
Temporal and Environmental Distribution

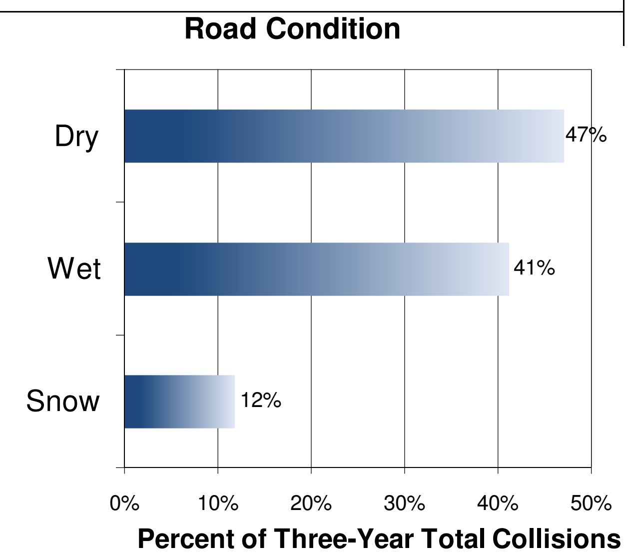
Temporal and environmental distributions are shown in Figure 9.





- Crashes occur during different months of the year with no apparent trend.
- The hourly crash distribution shows a crash trend during the afternoon between 1:00 PM and 2:00 PM. The majority or crashes occur between 8:00 AM and 6:00 PM.





- Eighty-eight percent of the collisions occurred during daytime hours indicating that lighting is not a contributing factor in collision frequency.
- More than half of collisions occurred under wet or snow covered road conditions. These trends indicated that weather may be a contributing factor in collision frequency.

Figure 9 - Temporal and Environmental Distribution

4.0 Existing Safety Measures

Photo	Existing Safety Measure
	***Dual Flashers*** Two overhead flashing beacons are displayed for each approach. This provides additional conspicuity of the intersection and reinforces the need for drivers to stop at the STOP control to clear cross through traffic.
	***Retroreflectivity*** During the night-time sight visit, many signs were observed to be in good condition to provide adequate sign retroreflectivity and conspicuousness during night-time hours. These sign conditions reflect the crash experience, where only twelve percent of crashes occurred during night-time hours.
	***Night-time Visibility*** The intersection is visible during night-time hours due to the overhead flashing signals and signs posted to the approach of the intersection. The conspicuity of the intersection provides drivers with adequate time to slow down and stop at the intersection during night-time hours.

5.0 Safety Issues

Operational stage safety issues have been identified in Section 5.1 and design stage safety issues have been identified in Section 5.2. Risk ratings have been identified for each safety issue, to rank the issues from highest risk/priority to lowest risk/priority. Possible mitigation measures have been identified in Section 6.0 to improve safety at the study intersection.

5.1 Operational Stage Safety Issues

Safety Issue 1: Sight Distance Obstruction

The majority of crashes at the intersection resulted in angle collisions. This trend may be due to various sight obstructions at the intersection. Temporary produce stands have been an issue in the past resulting in an obstruction on the southwest corner. Signs, warning of a civil infraction have been posted to prevent produce stands from being displayed in the right-of-way.

The majority of angle collisions involved a southbound traveling vehicle and a westbound traveling vehicle. This crash pattern is a result of the lack of an offset right-turn on the westbound approach. Drivers stopped on the southbound approach, may have limited sight distance due to westbound right turning vehicles, particularly large trucks that block vehicles traveling adjacent to them in the through lane. At least one fatal crash was a result of a truck turning right from the westbound approach obstructing the view between a motorcycle traveling adjacent to it and a southbound vehicle that chose an inadequate gap and was struck by the motorcycle.

Expected Crash Types: Angle
Expected Frequency: Frequent
Expected Severity: Extreme
Risk Rating: F

Safety Issue 2: Sign Deterioration

Signs provide guidance to drivers concerning the non-essential roadway. During site visits, the RSA team observed signs that were worn or beyond its useful life, limiting retroreflectivity and conspicuity, and in some cases becoming illegible, particularly during night-time hours. Signs in poor condition limit guidance and may result in sudden braking and erratic maneuvers for un-familiar drivers.

Expected Crash Types: Sideswipe, lost control, rear-end
Expected Frequency: Occasional
Expected Severity: Moderate
Risk Rating: C

Safety Issue 3: Limited Signing and Pavement Markings

Designated turn lanes are provided on the eastbound, westbound and southbound approaches to the inter-section. For drivers approaching the intersection at a high speed (55 mph), the designated turn lanes may not be apparent due to the lack of lane use signs and deteriorated or missing pavement markings. Lane use pavement markings exist for the southbound left-turn lane and the westbound right-turn lane. The desig-nated eastbound right-turn lane is unmarked. The ab-sence of pavement markings may make it difficult for drivers to determine the lane use. The lack of lane use signs and deteriorated or missing pavement markings may contribute to lane changing close to the intersec-tion and an increase in sideswipe collisions. Three sideswipe collisions occurred at or near the intersec-tion during the three year study period.

Expected Crash Types: Sideswipe
Expected Frequency: Occasional
Expected Severity: Low
Risk Rating: B

Safety Issue 4: Queuing	
The intersection experiences congestion in the southbound left-turn lane during peak hour times. The congestion contributes to long queues, which increases delay, and may result in rear-end collisions due to unexpected stopping.	 **Expected Crash Types:** Rear-end **Expected Frequency:** Occasional **Expected Severity:** Low **Risk Rating:** B

Safety Issue 5: Turning Radius	
Tire tracks on the northwest corner are evidence vehicles having difficulty making a southbound right turn. The tight turn radius requires vehicles, most likely large trucks, to mount the curb when making a southbound right turn. Therefore, the turning radius may not be large enough to comfortably accommodate large vehicles. This may result in a driver losing control of their vehicle while trying to track back onto the roadway.	 **Expected Crash Types:** Run-off-road **Expected Frequency:** Infrequent **Expected Severity:** Low **Risk Rating:** A

5.2 Preliminary Design Stage Safety Issues

Safety Issue 6: Snowmobile Activity

A snowmobile trail exists near the intersection and crosses across M-115 to the west of the intersection. The trail attracts heavy volumes of snowmobile road users and design requirements are needed to accommodate these road users.

During the site visits, pavement and shoulder deterioration was observed, where snowmobiles cross the roadway.

Expected Crash Types:	Snowmobile Related
Expected Frequency:	Rare
Expected Severity:	Extreme
Risk Rating:	C

Safety Issue 7: Signal Installation Design

A signal warrant has been performed by MDOT, and the results determined that the signal installation is not warranted. There is high risk involved with the installation of a signal at this intersection, due to the long stretch of unsignalized intersections on M-115. Drivers on M-115 would likely disregard the traffic signal and result in severe high speed crashes. Therefore, it was determined that a signal should not be installed at this intersection.

Expected Crash Types:	All
Expected Frequency:	Frequent
Expected Severity:	High
Risk Rating:	E

Safety Issue 8: All-Way Stop Design

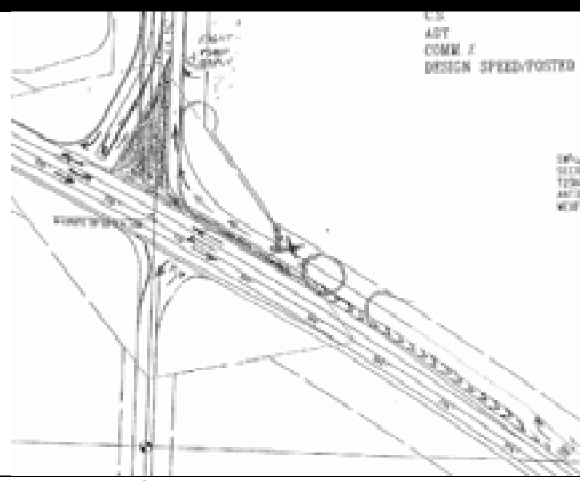
During the RSA preliminary findings meeting, an all-way stop control design was suggested. After consideration of the all-way stop control, the RSA team has determined that an all-way stop control on M-115 would have similar risks as a signal control. Drivers would not expect to have to stop on M-115 and this may result in an increase of serious injury crashes.

A multi-way stop study was conducted and it was determined that a multi-way stop is not warranted due to crash experience.   Therefore, it was determined that an all-way stop control should not be implemented at this intersection.

Expected Crash Types: All
Expected Frequency: Frequent
Expected Severity: High
Risk Rating: E

Safety Issue 9: Realigned Design

Realigning the intersection, as shown in the preliminary design provided by MDOT, would increase conflict points at the intersection. Although the design would improve the westbound right-turn movement, and conflicts associated with that movement, the offset of the north and south leg, would still result in crashes occurring at the intersection.



Expected Crash Types: All
Expected Frequency: Frequent
Expected Severity: High
Risk Rating: E

6.0 Suggested Improvements

Suggestion 1: Roundabout Installation

Consider installing the proposed roundabout design. The installation of a roundabout would increase safety at this intersection by reducing conflict points and vehicle speeds. Roundabouts typically result in a reduction in crash frequency, especially for left-turn and angle crashes[1]. The majority of crashes that resulted in angle collisions due to sight obstructions would be eliminated. In addition to reducing conflict points, the installation of a roundabout would also reduce injury severity. Twenty-four percent of crashes resulted in either a Fatal or B injury during the study period. Installing a roundabout would reduce the likelihood of these serious injury crashes from occurring.

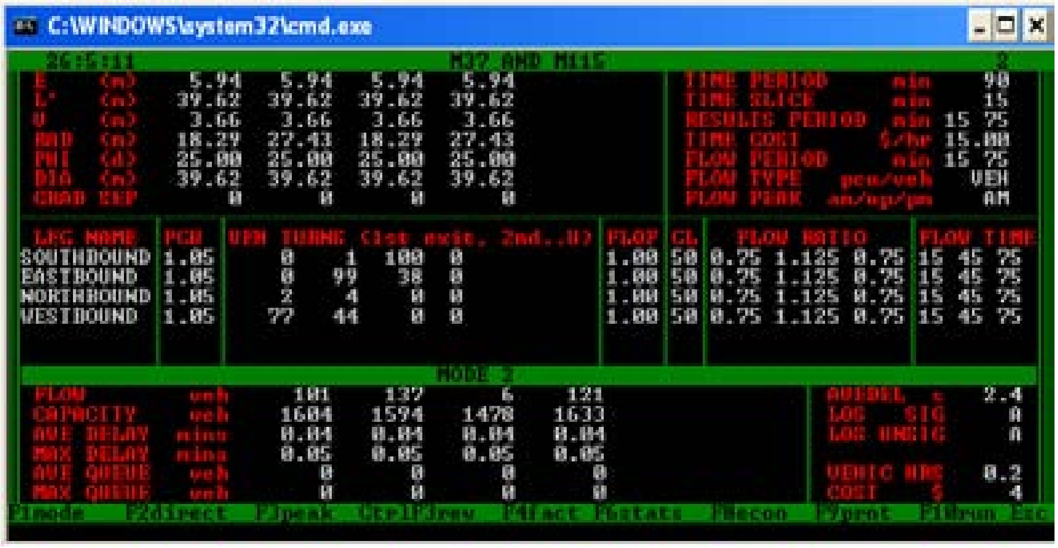
The installation of a roundabout would also reduce delay and queuing that occurs in the southbound left-turn lane. Drivers would no longer risk choosing inadequate gaps due to frustration because of long delays. Additionally, southbound rear-end collisions may be reduced when seasonal excessive queuing is reduced.

The installation of the roundabout should also accommodate snowmobile road users due to the trail that crosses west of the intersection. The proposed design should consider moving the crossing away from the proposed roundabout location to reduce driver workload at the roundabout. The snowmobile crossing should also be accommodated with concrete pavement to reduce surface deterioration. Adequate facilities for snowmobile road users with proper width and design would reduce the potential for damage and increase service life of the transportation facilities.

The intersection was analyzed using Rodel to determine the average delay encountered by vehicles during the AM and PM peak hours at a proposed roundabout. The Rodel output report and average calculated delays for each movement are summarized in Figure 10. Average delay described as a Level of Service, ranging from “A” (little or no delays) to “F” (congested conditions with considerable delays). The proposed roundabout is a one lane roundabout that consists of one lane in each approach and a right turn bypass lane for the southbound approach. The proposed roundabout was determined to operate at LOS A during the AM and PM peak hours.

[1] American Association of State Highway Transportation Officials (AASHTO). *Highway Safety Manual*, 1st Edition, Washington, DC, 2010

AM Peak Hour



PM Peak Hour

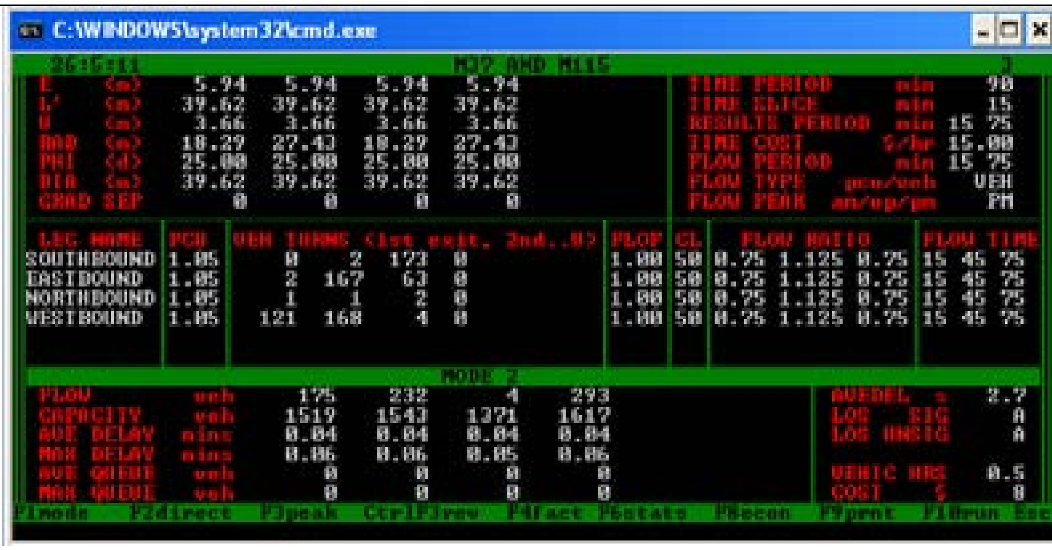


Figure 10 - Rodel Analysis

Predictive Modeling

Predictive modeling using the site-specific Empirical Bayes (EB) Method from the *Highway Safety Manual (HSM)*[2] *Volume 2* was applied to this intersection, in order to determine the crash reduction benefits of a roundabout installation. The HSM utilizes a predictive method to estimate expected average crash frequency as a function of traffic volume, roadway features and the severity of the predicted crashes.

[2] American Association of State Highway Transportation Officials (AASHTO). *Highway Safety Manual*, 1st Edition, Washington, DC, 2010.

To properly estimate crash frequency, the calibration factor was updated based on Michigan Calibration Factors that were provided by MDOT. This calibration factor represents the characteristics of the study area, a rural four legged intersection with a two-way stop approach. The calibration factor used in the HSM analysis was 1.56.

A base had to be established to determine the effectiveness of the potential mitigation measures. This was accomplished by establishing the predicted number of crashes estimated by using the Rural Two-Lane, Two-Way Roads safety performance function (SPF) outlined within the HSM. A SPF is an equation established in the HSM that estimates the expected average crash frequency as a function of traffic volume (ADT), roadway characteristics, and average observed annual crashes.

A crash modification factor (CMF) was then integrated into the SPF to determine the estimated crashes that would be expected if a roundabout was to be implemented. The CMF used was 0.29, which was collected from Table 14-4 in Volume 3 of the HSM.

Results of the HSM analysis are summarized in Table 4, and worksheets used in the analysis are provided in Appendix A.

Table 4 - HSM Analysis Results

Observed Annual Crash Frequency	Predicted Annual Crash Frequency	Predicted Annual Crash Frequency with Roundabout Installation
5.7	**6.3**	**1.8**

Table 4 shows that the crashes predicted by the HSM would be more than the observed crashes for the existing intersection configuration. The installation of a roundabout would have a crash reduction factor of 71 percent, and therefore the predicted annual crash frequency was much lower for the proposed roundabout intersection configuration.

Suggestion 2: Upgrade Signing

To improve night-time conspicuousness and visibility, replace signs that are beyond their useful life. The minimum retroreflective standard stated in the MUTCD[3] is that regulatory, warning, and guide signs shall be retroreflective or illuminated to show the same shape and similar color by both day and night. Refer to Section 2A.07 and 2A.08 in the MUTCD for more information on maintaining minimum retroreflectivity.

[3] MUTCD *Manual on Uniform Traffic Control Devices for Streets and Highways* 2003 Edition, U.S. Department of Transportation Federal Highway Administration, 2007.

Suggestion 3: Improve Pavement Markings

Restriping the roadway to provide new pavement markings would help reduce the risk of sideswipe crashes and reduce the likelihood of drivers veering from the travel way. In addition to new pavement markings, designated turn lanes should be marked with designated lane use pavement markings to inform drivers of the correct lane maneuver.

Consider using durable pavement markings, with the installation of a roundabout. Durable pavement markings have a longer service life, and have increased retroreflectivity during night-time hours. These pavement markings would also provide adequate guidance through the roundabout for more years, compared to painted pavement markings.

Suggestion 4: Re-evaluate Turning Radius

Re-evaluate the existing turning radius to determine whether a larger turning radius is needed for the proposed roundabout. An adequate turning radius would comfortably accommodate large vehicles turning right from the southbound direction.

Suggestion 5: Offset Right-turn Lane

In the interim, a low cost countermeasure that could potentially reduce crashes is the implementation of an offset right-turn lane[4]. An offset right-turn lane, would improve the sightline between drivers stopped on the southbound approach and westbound vehicles that would otherwise be blocked by a right turning vehicle. This implementation could reduce the likelihood of severe angle collisions occurring.

Figure 11 - Example of an Offset Right-turn[4]

[4] NCHRP Report 500, *Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*. Transportation Research Board, Washington, DC, 2003.

7.0 Economic Analysis

Mitigation measures are intended to increase the safety of the roadways by reducing the number of crashes and injuries within the study area. MDOT has provided a time-of-return (TOR) for the proposed roundabout installation. An economic evaluation has been conducted to estimate the potential societal benefits that may be attributed to the remaining suggested improvements.

7.1 Economic Evaluation Methodology

To determine the potential societal benefits of the proposed countermeasures, an economic evaluation was conducted. The benefits are related to collision characteristics such as severity and frequency, collision reduction potential, and average societal costs.

Societal costs have been based on estimates provided by the National Safety Council, which provides updated average comprehensive costs for motor vehicle crashes. The comprehensive costs include the calculable costs of collisions (wage and productivity losses, medical expenses, administrative expenses, motor vehicle damage, and employer costs) as well as the estimated value of the reduced quality of life. These costs are summarized in Table 5.

Table 5 - Estimated Costs of Collisions

SEVERITY	ESTIMATED COST
Fatal	$4,300,000
incapacitating injury (A)	*$216,800*
non-incapacitating injury (B)	*$55,300*
possible injury (C)	*$26,300*
Property Damage Only	$2,400

Source: *"Estimating the Costs of Unintentional Injuries, 2009" from the National Safety Council website www.nsc.org.*

For the purpose of the economic evaluation, the net annual operating costs, maintenance costs, and salvage values were assumed to be negligible. A discount rate of 3 percent was assumed. The crash reduction factors, shown in Table 6, have been derived from values provided by the Crash Modification Factors Clearinghouse website[5]. The costs and benefits of the proposed countermeasures, with the expected benefit-cost ratio, are summarized in Table 6.

[5] http://www.cmfclearinghouse.org/index.cfm

The formulas used to calculate the estimated annual benefit (EAB) and the benefit cost ratio (B/C) are shown below.

EAB = CRF*(4,300,000*Fatal crash/year + 216,800*A Injury crash/year + 55,300*B Injury crash/year + 26,300*C Injury crash/year + 2,400*PDO crash/year)

B/C = EAB/(cost*A/P)

where,
EAB = Estimated Annual Benefit
CRF = Crash Reduction Factor
A/P = Capital Recovery Factor at a discount rate of 3% (annual given present cost)

7.2 Results of the Evaluation

The costs and benefits of the proposed countermeasures are summarized in Table 6

Table 6 - Economic Evaluation of Suggested Improvements

IMPROVEMENT	ASSUMED SERVICE LIFE	ESTIMATED COST OF IMPROVE-MENT	EXPECTED CRASH REDUCTION (CRF)	ESTIMATED ANNUAL BENEFIT (EAB)	ESTIMATED BENEFIT: COST RATIO (B/C)
Upgrade signing	6 years	$10,000	10% (rear-end)	$160	0.1
Improve pavement markings	2 years	$5,000	10% (sideswipe, run-off-road)	$480	0.2
Re-evaluate turn-ing radius	15 years	$20,000	N/A	--	--
Offset right-turn lane	15 years	$20,000	69% (angle)	$1,021,039	609

N/A = crash reduction factor not available

APPENDIX A: HSM ANALYSIS

Worksheet 2A -- General Information and Input Data for Rural Two-Lane Two-Way Roadway Intersections

General Information		Location Information	
Analyst	JLY	Roadway	
Agency or Company	Opus	Intersection	M-115 and M-38
Date Performed	05/27/11	Jurisdiction	MDOT
		Analysis Year	2011

Input Data			Base Conditions	Site Conditions			
Intersection type (3ST, 4ST, 4SG)			--	4ST			
$AADT_{major}$ (veh/day)	$AADT_{MAX}$ = 14,700 (veh/day)		--	9,500			
$AADT_{minor}$ (veh/day)	$AADT_{MAX}$ = 3,500 (veh/day)		--	**4,200**			
Intersection skew angle (degrees)	[If 4ST, does skew differ for minor legs?]	No	0	Skew for Leg 1 (All):	30	Skew for Leg 2 (4ST only):	0
Number of signalized or uncontrolled approaches with a left-turn lane (0, 1, 2, 3, 4)			0	1			
Number of signalized or uncontrolled approaches with a right-turn lane (0, 1, 2, 3, 4)			0	2			
Intersection lighting (present/not present)			Not Present	Not Present			
Calibration Factor, C_i			1.00	1.56			

Worksheet 2B -- Crash Modification Factors for Rural Two-Lane Two-Way Roadway Intersections

(1) CMF for Intersection Skew Angle CMF_{1i} from Equations 10-22 or 10-23	(2) CMF for Left-Turn Lanes CMF_{2i} from Table 10-13	(3) CMF for Right-Turn Lanes CMF_{3i} from Table 10-14	(4) CMF for Lighting CMF_{4i} from Equation 10-24	(5) Combined CMF CMF_{COMB} (1)*(2)*(3)*(4)
1.18	0.72	0.74	1.00	0.63

Worksheet 2C -- Intersection Crashes for Rural Two-Lane Two-Way Roadway Intersections

(1) Crash Severity Level	(2) $N_{spf\ 3ST,\ 4ST\ or\ 4SG}$ from Equations 10-8, 10-9, or 10-10	(3) Overdispersion Parameter, k from Section 10.6.2	(4) Crash Severity Distribution from Table 10-5	(5) $N_{spf\ 3ST,\ 4ST\ or\ 4SG}$ by Severity Distribution $(2)_{TOTAL}$ * (4)	(6) Combined CMFs from (5) of Worksheet 2B	(7) Calibration Factor, C_i	(8) Predicted average crash frequency, $N_{predicted\ int}$ (5)*(6)*(7)
Total	7.573	0.24	1.000	7.573	0.63	1.56	7.423
Fatal and Injury (FI)	--	--	0.431	3.264	0.63	1.56	3.199
Property Damage Only (PDO)	--	--	0.569	4.309	0.63	1.56	4.224

Worksheet 2D -- Crashes by Severity Level and Collision Type for Rural Two-Lane Two-Way Road Intersections						
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Collision Type	**Proportion of Collision Type$_{(TOTAL)}$**	**N $_{predicted\ int\ (TOTAL)}$ (crashes/year)**	**Proportion of Collision Type$_{(FI)}$**	**N $_{predicted\ int\ (FI)}$ (crashes/year)**	**Proportion of Collision Type$_{(PDO)}$**	**N $_{predicted\ int\ (PDO)}$ (crashes/year)**
	from Table 10-6	$(8)_{TOTAL}$ from Worksheet 2C	from Table 10-6	$(8)_{FI}$ from Worksheet 2C	from Table 10-6	$(8)_{PDO}$ from Worksheet 2C
Total	1.000	7.423	1.000	3.199	1.000	4.224
		$(2)x(3)_{TOTAL}$		$(4)x(5)_{FI}$		$(6)x(7)_{PDO}$
SINGLE-VEHICLE						
Collision with animal	0.010	0.074	0.006	0.019	0.014	0.059
Collision with bicycle	0.001	0.007	0.001	0.003	0.001	0.004
Collision with pedestrian	0.001	0.007	0.001	0.003	0.001	0.004
Overturned	0.005	0.037	0.006	0.019	0.004	0.017
Ran off road	0.122	0.906	0.094	0.301	0.144	0.608
Other single-vehicle collision	0.008	0.059	0.004	0.013	0.010	0.042
Total single-vehicle crashes	0.147	1.091	0.112	0.358	0.174	0.735
MULTIPLE-VEHICLE						
Angle collision	0.431	3.199	0.532	1.702	0.354	1.495
Head-on collision	0.040	0.297	0.060	0.192	0.025	0.106
Rear-end collision	0.242	1.796	0.210	0.672	0.266	1.123
Sideswipe collision	0.101	0.750	0.044	0.141	0.144	0.608
Other multiple-vehicle collision	0.039	0.289	0.042	0.134	0.037	0.156
Total multiple-vehicle crashes	0.853	6.332	0.888	2.841	0.826	3.489

Worksheet 2E -- Summary Results for Rural Two-Lane Two-Way Road Intersections		
(1)	(2)	(3)
Crash severity level	**Crash Severity Distribution** (proportion)	**Predicted average crash frequency (crashes / year)**
	(4) from Worksheet 2C	(8) from Worksheet 2C
Total	1.000	7.4
Fatal and Injury (FI)	0.431	3.2
Property Damage Only (PDO)	0.569	4.2

Worksheet 3A -- Predicted and Observed Crashes by Severity and Site Type Using the Site-Specific EB Method

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Site type	**Predicted average crash frequency (crashes/year)**			**Observed crashes,** $N_{observed}$ (crashes/year)	**Overdispersion Parameter, k**	**Weighted adjustment, w**	**Expected average crash frequency,**
	$N_{predicted}$ (TOTAL)	$N_{predicted}$ (FI)	$N_{predicted}$ (PDO)			Equation A-5 from Part C Appendix	Equation A-4 from Part C Appendix
ROADWAY SEGMENTS							
Segment 1				0		1.000	0.0
Segment 2				0		1.000	0.0
Segment 3						1.000	0.0
Segment 4						1.000	0.0
Segment 5						1.000	0.0
Segment 6						1.000	0.0
Segment 7						1.000	0.0
Segment 8						1.000	0.0
INTERSECTIONS							
Intersection 1	7.423	3.199	4.224	5.7	0.240	0.360	6.3
Intersection 2						1.000	0.0
Intersection 3						1.000	0.0
Intersection 4						1.000	0.0
Intersection 5						1.000	0.0
Intersection 6						1.000	0.0
Intersection 7						1.000	0.0
Intersection 8						1.000	0.0
COMBINED (sum of column)	7.423	3.199	4.224	5.7	--	--	6.3

Worksheet 3B -- Site-Specific EB Method Summary Results

(1)	(2)	(3)
Crash severity level	$N_{predicted}$	$N_{expected}$
Total	$(2)_{COMB}$ from Worksheet 3A	$(8)_{COMB}$ from Worksheet 3A
	7.423	6.3
Fatal and Injury (FI)	$(3)_{COMB}$ from Worksheet 3A	$(3)_{TOTAL} * (2)_{FI} / (2)_{TOTAL}$
	3.199	2.7
Property Damage Only (PDO)	$(4)_{COMB}$ from Worksheet 3A	$(3)_{TOTAL} * (2)_{PDO} / (2)_{TOTAL}$
	4.224	3.6

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